

Replicated X-Ray Optics

William D. Jones/EB52
205-544-3479
E-mail: bill.jones@msfc.nasa.gov

The objective of this research is to demonstrate large, lightweight, high-performance x-ray optics. These optics will enable future x-ray astronomy missions such as the High Throughput X-Ray Mission (HTXS), which is now in the mission definition phase as a follow-on to the Advanced X-Ray Astrophysics Facility (AXAF).

The replicated x-ray optics program at MSFC began in 1992 when the design of the spacecraft for the spectroscopy portion of the AXAF mission (AXAF-S) was assigned to the Center. The baseline optics for this mission were grazing incidence epoxy replicated foil mirrors (Serlemits, et. al.). A group at MSFC proposed to develop electroformed nickel replica (ENR) mirror which would offer four to eight times better resolution than the baseline optics.

Grazing incidence mirrors are exactly analogous to the primary mirror of a conventional telescope—they collect the incident radiation and concentrate it onto the detector. The essential difference is that the wavelength of the incident light is much shorter—1 to 12 Å in the case of x-ray mirrors versus 4,500 to 7,000 Å for the mirrors in a visible light telescope. In order to obtain efficient reflection at these short wavelengths, the angle of incidence must be very nearly 90 degrees. At these very large angles of incidence, the incoming light “grazes” along the surface—hence the term grazing incidence optics. The very short wavelength also makes the performance of the mirrors very sensitive to slight irregularities in the surface. Even a slight roughening of the surface can cause scattering of the incident light, resulting in a “halo” surrounding each image.

Grazing incidence x-ray optics are manufactured by first creating a “master”—a form whose surface has the inverse shape

that the final optic should have. In the case of grazing incidence optics, the master has the appearance of two truncated cones with the base of the smaller cone joined to the larger cone at the plane of the truncation. The outer diameter of this shape (“mandrel”), which is typically made of aluminum, is covered with plated nickel-phosphor alloy, which is hard, amorphous, and can be polished to an extremely smooth surface. The proper optical shape (“prescription”) is machined into the plated surface, using an ultraprecision machine and a single-crystal diamond as a cutting tool. The surface is superpolished and is then ready for use to replicate the actual mirror.

To replicate a mirror, a thin (1,000 to 1,500 Å) film of gold is applied to the surface in a vacuum chamber. Then the mirror is placed in a nickel sulfamate plating bath, where a 0.1- to 1.0-mm thick layer of nickel is electrolytically deposited over the gold film. This process is controlled so there is negligible internal stress in the nickel to avoid warping the mirror later when it is removed from the mandrel. At the end of the plating process, the mandrel and mirror assembly is removed from the bath, cleaned and then is ready for removal of the mirror from the mandrel. To remove the mirror, the entire mandrel/mirror assembly is chilled. Since the core of the mandrel is aluminum and the mirror is nickel, the aluminum contracts more quickly when cooled than does the nickel. This results in a force developing which eventually exceeds the adhesion of the gold to the nickel-plated surface of the mandrel, causing the mirror to separate from the mandrel. The mirror can then be removed from the mandrel, and is ready for use. The mandrel is unharmed by this procedure and can be used to manufacture additional mirrors.

During the year, two grazing incidence replicated x-ray mirrors were manufactured and tested. These mirrors were 1/10-scale models of the innermost mirror pair used in the mirror assembly for the AXAF instrument and were ≈62 mm in diameter at

the large end, tapering over a length of 175 mm to a small end diameter of ≈59 mm. The first mirror had on-axis x-ray performance of ≈8 arc sec full width at half maximum and half-power diameters of ≈15 arc sec at a x-ray energy of 4.5 keV, increasing to 27 arc sec at 8.0 keV. The second mirror had slightly lower performance at the lower energy but was nearly the same at 8.0 keV. These results are much improved compared to the larger mirrors built in 1992 and 1993.

After x-ray tests of the initial set of mirrors, a series of experiments were conducted to make mirrors that were much lighter weight. Mirrors with a wall thickness as thin as 0.1 mm (0.004 in) were successfully electroformed and removed from a mandrel. Of course, the thinner the walls of the mirror, the more flexible the mirror becomes. To restore much of the stiffness lost when the walls are thinned, a mirror was made with external reinforcing rings at each end and in the center (fig.110). This mirror weighs only 20 percent of the mirrors which were tested earlier. This mirror (and others similar to it) are awaiting testing at MSFC.

The primary NASA program to benefit from this technology development is the High Throughput X-ray Spectroscopy Mission (HTXS) which has been proposed as a follow-on to the AXAF mission, scheduled for launch in September, 1998. The HTXS mission, as currently envisioned, would consist of six x-ray telescopes, each on a separate satellite. The mirror assembly of each of these satellites would consist of 80 individual x-ray mirrors, nested to save space. The HTXS mission schedule has baselined the launch of the first telescope in the 2004 to 2005 time frame.

The techniques for electroforming precision optics have a number of applications in the commercial sector, a few of which are described here:

- Low-cost precision optics. Most of the effort in the replicated optics process is in creating the master surface from which the replicas are made. Multiple replicas



FIGURE 110.—Ring-reinforced x-ray mirror.

can be generated at low unit cost. These optics could be used in mass-produced applications where the precision requirements exceed those obtainable from other replica materials such as plastic.

- Precision manufacturing of components. A nonoptical application of the low-stress process that has been refined in the research is electroforming components where close dimensional tolerances must be maintained. The low-stress technique helps insure that the shape of the finished part very closely duplicates that of the master surface used to create it. A specific case is creating replicas for pressing CD's (both digital audio and data (CD-DA and CD-ROM)). The replicas for pressing the individual CD's must be quite flat or the resulting product will be rejected. The low-stress process has been used to improve the yield in this manufacturing process.

Development of precision electroformed grazing incidence optics for x-ray applications continued during 1995 and 1996. Two mirrors manufactured at MSFC were tested and shown to have quite good performance. Additional mirrors with reduced weight have been manufactured and are awaiting testing.

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Biographical Sketch: William D. Jones is senior research engineer in the Optics Branch at MSFC. He is a graduate of the University of South Florida. ☐